AEROJET GENERAL

s131-DRM08-W187f4

MANUAL OF MATERIALS DATA RELEASE MEMORANDA

PART III: DRM 24 through 45

NERVA Program Contract SNP-1

APRIL 1971

K. Sato
Manager, Engineering Staff
Engineering Operations

Classification Category

UNCLASSIFIED

T. A. Rutherford 4/28/71

Classifying Officer Date

MATERIA: Al_2O_3 COATING

DRM: 24.01

REVISION: 0
DATE: 1-6-71

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

APPROVALS

ORIGINATOR: Ralph J. Fottila

REVIEW: [signature] 11 Jan '71

CLASSIFICATION: [signature] 12 Jan 71

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 24.01 PAGE NO. 2 DATE 1-6-71 MATERIAL Al_2O_3 Coating

CONDITION Flame or Plasma Arc Sprayed TEST DIRECTION

SPEC. NOS. FORM Rokide A

DATA BASIS Category "C" COMMENT

PROPERTY Solar Absorptance, α_s

COATING	SUBSTRATE	COATING THICKNESS INCHES	TYPICAL VALUE	VARIABILITY	ULTRAVIOLET & NEUTRON RAD DEGRADATION FACTOR %	DESIGN ALLOWABLE	REFERENCE
Al_2O_3	Aluminum Alloy	.006	.31	± .06	+ 40	.43	1, 2, 3
		.007	.30		+ 40	.42	1, 2, 3
		.010	.26		+ 40	.36	1, 2, 3
	Sand-blasted 2024-T3	.013	.32		+ 40	.45	1, 2, 3

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 24.01 PAGE NO. 3 DATE 1-6-71 MATERIAL Al_2O_3 Coating

CONDITION Flame or Plasma Arc Sprayed TEST DIRECTION

SPEC. NOS. FORM Rokide A

DATA BASIS Category "C" COMMENT

PROPERTY Total Hemispherical Emittance

COATING	SUBSTRATE & CONDITION	COATING THICKNESS INCHES	EMITTANCE AT TEMPERATURE -60°F	40°F	140°F	VARIABILITY	REFERENCE
Al_2O_3	Aluminum Alloy	.006	.70	.71	.71	± .06	1, 2, 3
		.007	.70	.71	.73		
		.010	.70	.71	.73		
	Sand-blasted 2024-T3	.013	.73	.75	.75	± .06	1, 2, 3

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 24.01 PAGE NO. 4 DATE 1-6-71 MATERIAL Al_2O_3 Coating

CONDITION Flame or Plasma Arc Sprayed TEST DIRECTION

SPEC. NOS. FORM Rokide A

DATA BASIS Category "C" COMMENT

PROPERTY Thermal Radiation (α_s/ε_H)

COATING	SUBSTRATE % CONDITION		COATING THICKNESS IN.		α_s/ε	VARIABILITY	
Al_2O_3	Aluminum Alloy		.010		.64*	± .06	

*Calculated using degraded value of α_s and lowest value of ε.

1. TEST MATERIAL

The coating is flame-sprayed Al_2O_3 (Rokide A) on an aluminum alloy substrate. The values listed are considered applicable to all aluminum alloy substrates, including AA 7075-T73, provided coating thickness is .010 in. or greater. Values are applicable for both plasma arc and flame spray coatings.

2. DATA ANALYSIS:

The nuclear radiation plus exposure to ultra-violet rays tends to degrade the optical properties of thermal control coatings. In general, the solar absorptance is primarily affected by increasing in value, and the total hemispherical emittance is relatively stable. The synergistic effect of nuclear radiation plus ultra-violet rays has not been determined on many coatings of interest, and, therefore, a degradation factor must be applied to published data to allow for these degradation mechanisms. After exposure to an integrated neutron flux of 10^{15} n/cm^2 (E < .48 ev), α_s of plasma sprayed alumina (Al_2O_3) increased from .16 to .19 or an increase of approximately 19%. The ε_H value remained stable. Similarly, Al_2O_3 exposed to 180 equivalent sun hours (ESH) showed signs of degradation (absolute values of α_s not given). On the basis of synergistic degradation (assumed) by ultra-violet and neutron radiation, the published values of α_s of flame arc sprayed Al_2O_3 are increased by 40%; this percentage being a conservative estimate of degradation.

The variability factor is $\pm$ .06 which is principally due to experimental technique of determining solar absorptance. The variation in values for the aluminum alloy and for 2024-T3 reflects the variability in experimental determination and deposition conditions.

The total hemispherical emittance is strongly dependent on the cleanliness condition of the surface. Because the usual surface condition of flame or plasma arc sprayed Al_2O_3 is rough, unless contaminated by dirt, the value of emittance is not expected to change markedly.

The thermal radiation property was calculated using maximum solar absorptance and minimum total hemispherical emittance.

3. REFERENCES

(1) Gaumer, R. E., and McKellar, L. A., Thermal Radiative Control Surfaces for Spacecraft, LMSD-704014, 1961.

(2) Breuch, R. A., and Pollard, H. E., Nuclear Environmental Effects on Spacecraft Thermal Control Coatings, Paper 39, Symposium on Thermal Radiation of Solids, NASA SP-55, 1964.

(3) Zerlaut, G. A., et al, "Ultraviolet Irradiation on White Spacecraft Coatings in Vacuum, Paper 41, NASA SP-55, 1964.

25 - ALUMINUM, PURE

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM TYPE:

DRM NO. 25.01

REV. NO. 0

SHEET 1 OF 3

SUBJECT: THERMAL RADIATIVE PROPERTIES OF ALUMINUM

DATE: 3-31-70

1. SCOPE:

Data for the following properties are attached:

Solar Absorptance
Emittance

2. TEST MATERIAL:

The test data are applicable to elemental aluminum as base or as vac. deposited.

3. DATA ANALYSIS:

The radiative properties of metals, coatings, and films are sensitive to surface condition, and if a coating or film, to its thickness, condition of substrate, and process used for deposition. The values listed are for polished surfaces; increasing surface roughness will increase the values.

4. CONCLUSIONS:

The values for the radiative properties are considered nominal and meaningful conservatism cannot be applied to provide data category classification

5. REFERENCE:

Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD 704104, 1961.

Thermophysical Properties of High Temperature Solid Materials, Vol. 1, Y. S. Touloukian, Macmillan Co., 1967

APPROVED BY / DATE	PREPARED FOR: / DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER / DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 25.01 PAGE NO. 2 DATE 3-31-70 MATERIAL Aluminum (Elemental)

CONDITION Base Material or as Vac. Deposited TEST DIRECTION

SPEC. NOS. FORM

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Emittance

TEMP °F	SURFACE	CONDITION					COMPUTED VALUE
	Polished to approximately 5μ surface finish.						
300							.05*
70							.04
-100							.035
-320							.03

*Rough surface, contamination or thicker coating would tend to increase emittance values.

COMMENTS: Thermophysical Properties of High Temperature Solid Materials, Vol. 1, Y. S. Touloukian, Macmillan Co., 1967.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 25.01 PAGE NO. 3 DATE 3-31-70 MATERIAL Aluminum

CONDITION Base Material or as Vac. Deposited TEST DIRECTION -

SPEC. NOS. - FORM All Forms

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Solar Absorptance

TEMP °F	SURFACE CONDITION	COMPUTED VALUE
	Chemically Clean	
40		.18*
	Vac. Deposited	
40		.20*

*The above properties subject to degradation by radiation and/or contamination.

COMMENTS: Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD 704014, 1961.

26 - VAPOR PRESSURE AND CONTAMINANT LIMITS

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 6	DRM NO. 26.01 REV. NO. 0

SUBJECT: METALLIC MATERIAL VAPOR PRESSURE AND MATERIAL CONTAMINANT LIMITS

DATE: 5-21-70

1. SCOPE:

Literature data were gathered and studied to determine a material vapor pressure limit and to set material contaminant limits for metallic materials used on the NERVA engine.

2. DATA ANALYSIS:

Data from several sources were studied, along with the experimental techniques, to evaluate their credibility and their usefulness to this application. To evaluate whether or not loss of material by direct evaporation or sublimation is significant, the rate of evaporation is calculated using the Langmuir equation

$$W = \frac{P}{17.14}\sqrt{M/T}$$

W $\frac{gm}{cm^2\text{-sec}}$ = rate of evaporation or sublimation

P torr = vapor pressure of the material

M $\frac{gms}{mol}$ = molecular weight in gas phase

T °K = temperature

The Langmuir equation predicts the maximum sublimation rates of unalloyed elements. Calculations made on the basis of .040 and .010 in. maximum sublimation in a year's exposure provide a maximum exposure temperature for several commonly used elements in space (UHV) vacuum as tabulated in Table 1.

The observed rate is always lower. Loss of one volatile component from an alloy is more difficult to predict. For solid solutions, Raoult's Law may be used for an approximation. For other alloy systems, such as eutectics, the vapor pressure of the alloy can be higher than that of its components. When the low vapor pressure element is present in high concentration, sublimation will proceed from grain boundaries and surfaces until the volatile element is depleted at the surface. Thereafter, the sublimation rate will be diffusion controlled, and diffusion generally does not take place at the temperatures in question.

APPROVED BY	DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER	DATE
T. E. Kelly			28 May

SUBJECT: METALLIC MATERIAL VAPOR PRESSURE AND MATERIAL CONTAMINANT LIMITS

DATE: 5-21-70

The evaporated atoms, in space atmosphere, will travel in straight lines and deposit only on surfaces which are cooler than the source and in an optical line of sight with the source.

Loss of material by direct evaporation in the low-pressure environment of space is insignificant for Al, Fe, Be, Ti, and the refractory metals and their alloys, at all temperatures up to their melting points. However, Zn, Cd, Mg, Hg, As, and yellow brass (Zn present) will sublime at a significant rate in space environment at 400°F (greater than .040 in./yr) and should not be used. Most ceramics and refractory compounds have very low vapor pressures at ordinary temperatures.

A vapor pressure limit of 10^{-7} torr at 400°F (860°R) has been specified by ANSC Specifications EC-90177 and EC-90179 for metallics used in the wiring harness and the engine instrumentation. These specifications also limit the inclusion in materials of the elements lithium, boron, and cobalt to 0.1 weight percent maximum.

The following data sheets also list the vapor pressure of less known metallic elements which may sublime at an appreciable rate within the specification limits of temperature and pressure in the space environment.

TABLE 1

TEMPERATURE AT WHICH SOME COMMON STRUCTURAL MATERIALS WILL LOSE 0.040 IN./YR IN ULTRA-HIGH SPACE VACUUM (2×10^{-14} torr or lower)

MATERIAL	TEMPERATURE °F	TEMPERATURE °R
Cd	248	708
Zn	324	784
Mg	464	924
Sn	1472	1932
Al	1490	1950
Be	1544	2004
Fe	1922	2382
Ti	2282	2742

TEMPERATURE AT WHICH SOME COMMON STRUCTURAL MATERIALS WILL LOSE 0.010 IN./YR IN ULTRA-HIGH SPACE VACUUM (2×10^{-14} torr or lower)

MATERIAL	TEMPERATURE °F	TEMPERATURE °R
Cd	207	667
Zn	291	751
Mg	397	857
Al	1341	1801
Be	1540	2000

REFERENCE: Space Materials Handbook, National Aeronautics and Space Administration, Third Edition, 1969.

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-26 PAGE NO. 4 DATE 5-21-70 MATERIAL Several with vapor pressures of 10^{-7} torr or lower.

CONDITION – TEST DIRECTION –

SPEC. NOS. – FORM –

DATA BASIS – COMMENT –

PROPERTY Vapor Pressure of Metals

TEMP °R	TEMP °K	VAPOR PRESSURE (TORR) ELEMENT Zn	Cd	Hg	Mg	As	As_2	As_4
585	325							1.31×10^{-7}
	375		1.98×10^{-7}					
720	400						2.8×10^{-12}	1.48×10^{-5}
810	450	8.13×10^{-7}			6.32×10^{-9}	6.1×10^{-24}		
855	475	4.90×10^{-6}	3.68×10^{-4}	20.4				
900	500				3.17×10^{-7}			

TEMP °R	TEMP °K	VAPOR PRESSURE (TORR) ELEMENT Se_2	Se_4	ΣSe	Te_2	ΣTe
720	400	3.53×10^{-7}	1.42×10^{-6}	1.77×10^{-1}		
810	450	3.41×10^{-5}	1.81×10^{-4}	2.15×10^{-4}	1.64×10^{-8}	1.64×10^{-8}
900	500				1.65×10^{-6}	1.65×10^{-6}

REFERENCE: An. N. Nesmeyanov, "Vapor Pressure of the Elements," Academic Press, New York, 1961

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-26 PAGE NO. 5 DATE 5-21-70 MATERIAL Several with Vapor Pressures 10^{-7} torr or lower

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS _____ COMMENT _____

PROPERTY Vapor Pressure of Metals

TEMP °R	°K	VAPOR PRESSURE (TORR) ELEMENT Na	Na_2	K	K_2	P_4 (White)	P_4 (Red)
583	325			1.9×10^{-7}			
675	375	1.54×10^{-7}				3.63	2.46×10^{-7}
855	475	1.77×10^{-4}	4.695×10^{-7}	6.840×10^{-3}	6.03×10^{-6}		

TEMP °R	°K	VAPOR PRESSURE (TORR) ELEMENT S_2	S_4	S_6	S_8
810	450	1.59×10^{-4}	7.23×10^{-5}	1.96×10^{-1}	5.8×10^{-1}

REFERENCE: An. N. Nesmeyanov, "Vapor Pressure of the Elements," Academic Press, New York, 1961

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. DRM M-26 PAGE NO. 6 DATE 5-21-70 MATERIAL

CONDITION TEST DIRECTION

SPEC. NOS. FORM

DATA BASIS COMMENT

PROPERTY Vapor Pressure of Metals

T		VAPOR PRESSURE TORR						
		ELEMENT						
°R	°K	Rb	Rb_2	Cs	Cs_2	Fr	Po	Po_2
450	250					1.24×10^{-7}		
495	275			1.068×10^{-7}				
540	300	3.307×10^{-7}						
675	375				1.56×10^{-7}			
720	400		4.767×10^{-7}					
810	450						7.65×10^{-7}	7.65×10^{-7}
855	475	3.905×10^{-2}	8.112×10^{-5}	1.07×10^{-1}	8.23×10^{-6}	6.92×10^{-2}	2.65×10^{-5}	3.30×10^{-5}

REFERENCE: An. N. Nesmeyanov, "Vapor Pressure of the Elements," Academic Press, New York, 1961.

27 - LEAD

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	Lead DRM NO. 27.01 REV. NO. 0

SUBJECT: DESIGN THERMOPHYSICAL PROPERTIES OF LEAD DATE: 5-22-70

1. SCOPE:

The following thermophysical properties of lead are attached:

Specific Heat
Thermal Conductivity
Coefficient of Linear Thermal Expansion
Density

2. TEST MATERIAL:

The data are applicable to high purity 99.998% lead.

3. DATA ANALYSIS:

The specific heat values are estimated to be within ± 5% of the true values at low, moderate and elevated temperatures. For temperatures below -423°F, the values are estimated to be ± 10% of true values.

Thermal conductivity values are the recommended values after experimental data analysis was made by the Thermophysical Property Research Center. As a result of the analysis, the values are estimated to be within ± 3% of the true values at moderate temperatures, ± 5% at elevated temperatures, and ± 10% at low temperatures.

The density values were calculated using the mean coefficient of linear thermal expansion. The density values are estimated to be within ± 5% of the true values.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE 26 May 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE C_p

DRM NO. 27.01 PAGE NO. 2 DATE 5-22-70 MATERIAL Lead

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT High Purity

PROPERTY Specific Heat

TEMP °F	BTU/LB °F		TEMP °F	BTU/LB	COMPUTED VALUE
-456.506	1.33×10^{-5}		- 98.25	2.975×10^{-2}	
-455.812	4.52×10^{-5}		- 52.80	3.008×10^{-2}	
-453.552	9×10^{-5}		- 5.50	3.054×10^{-2}	
-451.626	2.33×10^{-4}		80.25	3.098×10^{-2}	
-434.11	7.53×10^{-3}		157.8	3.10×10^{-2}	
-431.27	8.688×10^{-3}		247.8	3.16×10^{-2}	
-429.09	1.038×10^{-2}		337.8	3.20×10^{-2}	
-423.40	1.287×10^{-2}		427.8	3.25×10^{-2}	
-410.89	1.737×10^{-2}		499.8	3.29×10^{-2}	
-392.13	2.200×10^{-2}		607.8	3.34×10^{-2}	
-363.44	2.527×10^{-2}				
-343.43	2.629×10^{-2}				
-314.9	2.730×10^{-2}				
-242.93	2.864×10^{-2}				
-201.48	2.914×10^{-2}				
-127.54	2.967×10^{-2}				

COMMENTS: Table 1021, Data Book, Thermophysical Properties Center, June 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE k

DRM NO. 27.01 PAGE NO. 3 DATE 5-22-70 MATERIAL Lead

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM All

DATA BASIS Category B COMMENT High Purity

PROPERTY Thermal Conductivity

TEMP °F	K BTU/FT-HR-°F			TEMP °F	BTU/FT-HR-°F		COMPUTED VALUE
-459.7	0			-369.7	25.2		
-457.9	1600			-333.7	24.2		
-456.1	2450			-315.7	23.8		
-454.3	1960			-189.7	22.2		
-452.5	1300			- 99.7	21.7		
-450.7	797			32	21.2		
-447.1	283			80.3	21.0		
-441.7	102			170.3	20.7		
-432.7	48.6			260.3	20.4		
-423.7	34.1			440.3	19.6		
-414.7	29.3			620.3	18.3		
-405.7	21.6						
-387.7	26.1						

COMMENTS: REFERENCE - Table 1012R, Data Book, Thermophysical Properties Center, December 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE ∝

DRM NO. 27.01 PAGE NO. 4 DATE 5-22-70 MATERIAL Lead

CONDITION Annealed TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F	IN./IN. °F X 10^{-6}	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE
-415	8.06						
-370	12.0						
-325	13.22						
-280	13.89						
-190	14.72						
-100	15.28						
- 10	15.72						
80	16.06						
170	16.28						
260	16.56						
440	17.83						

COMMENTS: REFERENCE - Kirby, Richard K. (NBS), Section 4f, American Institute of Physics Handbook, 2nd ed., 1963.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE ρ

DRM NO. 27.01 PAGE NO. 5 DATE 5-22-70 MATERIAL Lead

CONDITION Annealed TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS COMMENT

PROPERTY Density

TEMP °F	ρ gm/cc	ρ lbs-cu in.	N_e	$\overline{X}$	K	S	COMPUTED VALUE
-415	11.59	.418					
-370	11.57	.417					
-325	11.55	.416					
-280	11.53	.415					
-190	11.49	.414					
-100	11.44	.412					
- 10	11.39	.411					
80	11.34	.409					
170	11.29	.407					
260	11.24	.405					
440	11.13	.402					

COMMENTS: Calculated on the basis of 11.34 gms/cc density at 80°F using coefficient of linear thermal expansion listed on accompanying sheet.

28 - GRAPHITE - 3% BORON COMPOSITE

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. 28.01 REV. NO.

SUBJECT: DESIGN ALLOWABLES FOR GRAPHITE - 3% BORON COMPOSITE

DATE: 6-17-70

1. SCOPE:

The following properties for graphite-3% boron composite are attached:

Specific Heat
Thermal Conductivity
Density

2. TEST MATERIAL:

Data for this composition graphite do not exist. All data are estimated or calculated based upon ATJ graphite data which is considered to be the base material.

3. DATA ANALYSIS:

The specific heat data were calculated on the basis of 97% of values for manufactured graphites. The values are estimated to be ± 15% of the true values.

Thermal conductivity of this composition was calculated in the perpendicular and parallel directions using the data for ATJ graphite of 1.73 gm/cc density. Because of the lack of experimental data, the conductivity was calculated on the basis of 80% of the conductivity of ATJ. Because the processing parameters for this alloy have not been established, it is estimated that the values listed will be within ± 25% at temperatures below -300°F and ± 20% at temperatures above -300°F of the projected true values of thermal conductivity of this composite.

A density of .061 $lb/in.^3$ at room temperature was assumed based on using ATJ process schedule. Density for other temperatures was not calculated because of the lack of thermal expansion data. The density listed is estimated to be within ± 10% of the projected true density.

4. CONCLUSIONS:

The data are considered category "D", a conservative engineering estimate of the properties listed based on the ATJ process schedule. This revision issued to include uncertainty range.

APPROVED BY DATE	PREPARED FOR: L. Stanley DATE:	COMPONENT/ ASSEMBLY IDENT Shield
PREPARED BY 6/18/70	AUTHORIZED CLASSIFIER DATE 22 June	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 28.01 PAGE NO. 2 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION _____ TEST DIRECTION All

SPEC. NOS. .061 lbs/in.^{3} density FORM minimum.

DATA BASIS No Category Required COMMENT Uncertainty, ± 15%

PROPERTY Specific Heat

TEMP °F		C_p BTU/LB/°F
0		0
-379	(a)	.00844
-370	(b)	.00980
-280	(b)	.0325
-190	(b)	.0624
-100	(b)	.0965
- 10	(b)	.132
80	(b)	.167
260	(b)	.238
350	(b)	.268
440	(b)	.294
530	(b)	.313
620	(b)	.330
710	(b)	.345
800	(b)	.359
890	(b)	.371
980	(b)	.381
1070	(b)	.390

(a) Table 5B.05.01, Specific Heat of Manufactured Graphite, The Industrial Graphite Engineering Handbook, Union Carbide Corp., April 1964.

(b) Kelly, B. T., and Walker, Jr., P. L., "Theory of Thermal Expansion of a Graphite Crystal in the Semi-Continuum Model," Carbon, March 1970.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 28.01 PAGE NO. 3 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION - TEST DIRECTION With Grain Direction

SPEC. NOS. - FORM Molded

DATA BASIS Category "D" COMMENT Uncertainty, ± 25% at temperatures below -300°F, + 20% at temps above -300°F

PROPERTY Thermal Conductivity

TEMP °F		BTU/ HR/FT/ °F					
-459.7		0					
-441.7		.226					
-423.7		1.2					
-405.7		2.8					
-369.7		7.9					
-351.7		11.5					
-333.7		14.8					
-315.7		19.0					
-297.7		22.6					
-189.7		43.4					
- 99.7		55.4					
- 9.7		60.6					
32		61.0					
80.3		60.1					
170.3		57.8					
260.3		55.0					
440.3		49.4					
620.3		44.4					
800.3		40.2					
980.3		36.5					

Touloukian, Y. S., Thermophysical Properties Research Center Data Book

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 28.01 PAGE NO. 4 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION _____ TEST DIRECTION Across Grain Directior

SPEC. NOS. _____ FORM Molded

DATA BASIS Category "D" COMMENT Uncertainty, ± 25% at temps below -300°F, ± 20% a: temps above -300°F.

PROPERTY Thermal Conductivity

TEMP °F		BTU/HR/ FT/°F					
-459.7		0					
-441.7		.184					
-423.7		.9					
-405.7		2.8					
-369.7		6.0					
-351.7		8.3					
-333.7		13.0					
-315.7		13.8					
-297.7		16.6					
-189.7		31.0					
- 99.7		39.8					
- 9.7		44.8					
32		45.3					
80.3		45.3					
170.3		43.9					
260.3		42.1					
440.3		37.9					
620.3		34.2					
800.3		31.0					
980.3		28.2					

Touloukian, Y. S., Thermophysical Properties Research Center Data Book

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 28.01 PAGE NO. 5 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION - TEST DIRECTION All

SPEC. NOS. - FORM Molded

DATA BASIS Category "D" COMMENT Uncertainty ± 10%

PROPERTY Density

TEMP °F		LBS/IN.^{3}					
80		.061					

Calculated value based on ATJ process schedule.

29 - 310 STAINLESS STEEL

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 7	DRM NO. 29.01 REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR 310 STAINLESS STEEL WROUGHT PRODUCTS, ANNEALED

DATE: 6-11-70

1. SCOPE:

Literature data were analyzed to estimate a design allowable for stainless steel alloy 310 wrought products.

2. TEST MATERIAL:

Unspecified wrought products annealed at 2150°F, 0.750-in. diameter bar, and annealed .062-in. sheet tensile test results are reported in References 1 through 3.

3. DATA ANALYSIS:

The test data were analyzed to obtain conservative design allowables for 310 stainless steel sheet and bar. The quantity of raw tensile data available for 310 stainless steel was small; however, estimates of the means and among- and within-lot variances were made from the available data. Since the sheet data came from only one heat, the lot-to-lot variance of the bar data was combined with the within-lot variance of the sheet data to estimate the combined within- and among-group standard deviation.

4. CONCLUSION:

Data are classified as category "C" since engineering judgement was used to estimate the design allowables for sheet and the degrees of freedom associated with the estimate of the random variance was less than 15.

5. REFERENCES:

(1) "Report on the Elevated Temperature Properties of Stainless Steel," ASTM Report STP 124, January 1952.

(2) K. A. Warren and R. P. Reed, "Tensile and Impact Properties of Selected Materials from 20° to 300°K," NBS Monography 63, June 1963.

(3) A. S. Rabensteine, "Mechanical Properties of 310, 316 and 316L Stainless Steel Sheet Alloys at Elevated Temperatures," Contract AF 33(657)-8706, Project 281, The Marquardt Corp., Van Nuys, Calif., dated 1 Dec. 1962.

APPROVED BY / DATE	PREPARED FOR: E. Bair DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER / DATE	

TPA

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 29.01 PAGE NO. 2 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.750-in. diameter bar

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	2	6	8	85	4.143	3.94	68.7
-320	1	3	8	156	4.143	3.9	140.0
-423	1	4	8	182	4.143	5.0	161

COMMENTS: References (1) and (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 29,01 PAGE NO. 3 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.750-in. diameter bar

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	2	6	8	32	4.143	2.13	23.2
-320	1	3	8	70	4.143	1.41	70.0
-423	1	3	8	99.5	4.143	1.34	88.9

COMMENTS: References (1) and (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 29.01 PAGE NO. 4 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.750-in. diameter bar

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	2	7	11	53.4	3.852	5	34.4
-320	1	3	11	67.0	3.852	4	51.6
-423	1	4	11	47.7	3.852	4.1	31.9

COMMENTS: References (1) and (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 29.01 PAGE NO. 5 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.062-in. sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	1	7	6	84.8	4.642	2.98	71.0

COMMENTS: References (1) and (3).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 29.01 PAGE NO. 6 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.062-in. sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	1	7	6	40.3	4.642	1.56	33.1

COMMENTS: References (1) and (3).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 29.01 PAGE NO. 7 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.062-in. sheet

DATA BASIS COMMENT

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$ %	K	S	COMPUTED VALUE %
RT	1	7	6	47.7	4.642	4.1	28.7

COMMENTS: References (1) and (3).

31 - AISI 9310 STAINLESS STEEL

MATERIAL: AISI 9310 STEEL

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

MATERIAL	FORM	CONDITION	PROPERTY	DATA CATEGORY	PAGE
AISI 9310 Steel	Bar	Quench + Temper (Uncarburized)	Tensile Strength	C	2
AISI 9310 Steel	Bar	Quench + Temper (Uncarburized)	Yield Strength	C	3
AISI 9310 Steel	Bar	Quench + Temper (Uncarburized)	% Elongation	C	4
AISI 9310 Steel	Bar	Carburized or Uncarburized	Elastic Modulus	D	5
AISI 9310 Steel	Bar	Carburized or Uncarburized	Poisson's Ratio	D	6
AISI 9310 Steel	Bar	Carburized or Uncarburized	Density	D	7
AISI 9310 Steel	Bar	Carburized or Uncarburized	Thermal Expansion	D	8

APPROVAL

ORIGINATOR: R. J. Coffelt

REVIEW: D. J. Lawrence 11/10/70

CLASSIFICATION: A. W. Fenn 11/10/70

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 2 DATE 11-9-70 MATERIAL AISI 9310 (Core - not Carburized)

CONDITION 1450°F Oil Quench Tempered at 300°F TEST DIRECTION

SPEC. NOS. AMS 6260 FORM Bar

DATA BASIS Category "C" COMMENT Values applicable to 1.0 in. rd. bar core only.

PROPERTY Tensile Ultimate Strength, ksi

TEMP °F	DIA.	MEAN VALUE	TYPICAL DATA VARIABILITY ksi	FACTOR OF CONSERVATISM	COMPUTED VALUE (ksi)	DATA CATEGORY	REFERENCE
RT	1"	159	± 10	± 14 ksi	135	C	1
-320	1"	210	± 15	± 15 ksi	180	C	2
-423	1"	230	± 15	± 15 ksi	200	C	2
RT	4"	136	± 10	± 11 ksi	115	C	1
-320	4"	190	± 15	± 15 ksi	160	C	2
-423	4"	220	± 15	± 15 ksi	190	C	2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 3 DATE 11-9-70 MATERIAL AISI 9310 (Core - Not Carburized)

CONDITION 1450°F Oil Quench Tempered at 300°F TEST DIRECTION

SPEC. NOS. AMS 6260 FORM Bar

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength, ksi

TEMP °F	DIA.	MEAN VALUE ksi	TYPICAL DATA VARIABILITY ksi	FACTOR OF CONSERVATISM	COMPUTED VALUE	DATA CATEGORY	REFERENCE
RT	1"	122	± 10	± 12	100	C	1
-320	1"	170	± 15	± 15	140	C	2
-423	1"	205	± 15	± 15	175	C	2
RT	4"	95	± 10	± 5	80	C	1
-320	4"	160	± 15	± 15	130	C	2
-423	4"	190	± 15	± 15	160	C	2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 4 DATE 11-9-70 MATERIAL AISI 9310 (Core - Not Carburized)

CONDITION Carburized, Quenched, Tempered at 300°F TEST DIRECTION

SPEC. NOS. AMS 6260 FORM

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, %

TEMP °F	DIA.	MEAN VALUE %	FACTOR OF CON-SERVATISM	ALLOWABLE %	DATA CATEGORY	REFERENCE
RT	1"	16	.37	10	C	1
-320	1"	20	.4	12	C	2
-423	1"	18	.5	9	C	2
RT	4"	19	.37	12	C	1
-320	4"	23	.4	14	C	2
-423	4"	22	.5	11	C	2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 5 DATE 11-9-70 MATERIAL AISI 9310

CONDITION Carburized, Quenched and Tempered TEST DIRECTION

SPEC. NOS. AMS 6260 FORM Tensile Bar

DATA BASIS Category "D" COMMENT Estimated equal to 4340

PROPERTY Elastic Modulus

TEMP °F		E X 10^6 psi	FACTOR OF CON-SERVATISM	DATA CATEGORY	REFERENCE		
RT		29	± 5%	D	3		
-423		30.5	± 5%	D	4		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 6 DATE 11-9-70 MATERIAL Carburized 9310

CONDITION Carburized, Quenched and Tempered TEST DIRECTION

SPEC. NOS. AMS 6260 FORM

DATA BASIS Category "D" COMMENT Poisson's Ratio for low alloy steels used as a close approximation to 9310.

PROPERTY Poisson's ratio

TEMP °F		POISSON'S RATIO	FACTOR OF CONSERVATISM	DATA CATEGORY	REFERENCE		
RT		.287	± 5%	D	4		
-423		.272	± 5%	D	4		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 7 DATE 11-9-70 MATERIAL AISI 9310

CONDITION Carburized, Quenched and Tempered TEST DIRECTION

SPEC. NOS. AMS 6260 FORM

DATA BASIS Category "D" COMMENT Density at RT is for low alloy steels. Density at -423°F calculated from RT density and thermal expansion data.

PROPERTY Density

TEMP °F		DENSITY LB/IN.^{3}	FACTOR OF CON-SERVATISM	DATA CATEGORY	REFERENCE		
RT		0.283	± 5	D	3		
-423		0.285	± 5	D	3		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 31.01 PAGE NO. 8 DATE 11-9-70 MATERIAL AISI 9310

CONDITION Carburized, Quenched and Tempered TEST DIRECTION

SPEC. NOS. AMS 6260 FORM

DATA BASIS Category "D" COMMENT The thermal expansion of low alloy steels was used as a close approximateion to that of 9310.

PROPERTY Thermal Expansion

TEMP °F		α 10^{-6} IN./IN.-°F	FACTOR OF CON-SERVATISM	DATA CATEGORY	REFERENCE		
200		6.3	± 5	D	3		
RT					3		
-320		4.63	± 5	D	4		
-423		3.29	± 5	D	4		

1. MATERIAL:

Material of the following heat treatment is applicable:

1700°F - 8 hours (box cool)
1450°F oil quench
Temper 300°F - 2 hours

Tensile properties are provided for uncarburized material that will be representative of core or interior material of carburize case hardened material. Tensile properties for the carburized case or case-core gradient material are not available. Physical property values are applicable for both uncarburized and carburized material.

2. DATA ANALYSIS:

From the literature, analysis of typical data showed a variability of room temperature strength due to composition and heat treat response of ± 10 ksi. An additional 14 and 12 ksi for Ftu and Fty, respectively, were subtracted to provide a minimum conservative estimate for 1-in. round design allowable. Additional 11 and 5 ksi values for Ftu and Fty, respectively, were subtracted for conservatism to obtain minimum estimate of 4-in. round design allowable.

The -320 and -423°F data were estimated from 9310 bar (diameter not specified) data adjusted to correspond to level of typical room temperature strengths established above. Typical composition and heat treat data variability were estimated to be ± 15 ksi with additional 15 ksi subtracted for conservatism to obtain minimum estimated design allowable.

The elongation at room temperature of both the 1-in. and 4-in. round are reported test data; the values of elongation at -320 and -423°F were estimated based on elongation data for the alloy (size not specified), adjusted for difference in reported room temperature values. The elongation at RT for the 4-in. round is greater because of the lower strength which is attributed to slower heat treat response (mass effect). The large variability in elongation data observed for steels resulted in a large factor of conservatism used to establish the minimum allowable elongations. For RT values, the minimums are approximately 63% of reported typical; for -320°F, approximately 60% of reported typical; and for -423°F, 50% of reported typical.

Elastic modulus, Poisson's ratio, thermal expansion and density were estimated on low alloy steels data for these properties as listed in Mil-Handbook-5.

3. REFERENCES:

(1) Modern Steels and Their Properties, Bethlehem Steel Co., 1952.

(2) "Typical Low Temperature Mechanical Properties of Several Materials," MPR3-251-369, Rocketdyne, NAA, Canoga Park, Ca., 14 November 1963.

(3) Military Handbook 5A, 5 January 1970.

(4) Cryogenic Materials Handbook, Supplement 4, Vol. II, August 1968.

32.01 - BRONZE BEARING ALLOYS

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 9	DRM NO. 32.01 REV. NO. 0

SUBJECT: Design Allowables For Bronze Bearing Alloys DATE: 7-15-70

1. SCOPE:

The design allowable for three grades of a bearing metal of the nominal composition 70% Cu-tin-lead are attached

2. TEST MATERIAL

Test data for this material were obtained from the literature.

3. DATA ANALYSIS

Technical data for bearings of this composition were reviewed and conservative estimate of allowable property limits were established. The tensile properties were set at 80% of average; coefficient of friction was increased approximately 50% to allow for environmental effects (atmosphere and temperature), variability limits were set for the reported thermal and physical properties.

4. CONCLUSIONS

The data are rated category "C", a conservative estimate of design allowables.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE 17 July 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 2 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

SPEC. NOS. - FORM -

DATA BASIS Category C COMMENT Grade B-4 - 70% Cu - 4% Sn - 26% Pb
Grade B-8 - 70% Cu - 8% Sn - 22% Pb
Grade B-10 - 70% Cu - 10% Sn - 20% Pb

PROPERTY Coefficient of Friction, μ

TEMP °F	GRADE	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE
RT	B-4						.20
	B-8						.22
	B-10						.25

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 3 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT -

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE ksi
RT	B-4						17
	B-8						19
	B-10						21

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 4 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT -

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE ksi
RT	B-4						8
	B-8						10
	B-10						13

COMMENTS: 'Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 5 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS.

DATA BASIS Category C COMMENT -

PROPERTY Elongation,%

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE %
RT	B-4						12
	B-8						8
	B-10						6

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 6 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty, -5% +20%

PROPERTY Modulus of Elasticity, E

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE psi x 10^6
RT	B-4						10
	B-8						10
	B-10						10

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 7 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty ± 10%

PROPERTY Modulus of Rigidity, G

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE psi x 10^6
RT	B-4						3.0
	B-8						3.3
	B-10						3.7

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 8 DATE 7-15-70 MATERIAL Bearings

CONDITION _____ TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Fb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty ± 5%

PROPERTY Density

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE lbs/in^3
RT	B-4						.334
	B-8						.324
	B-10						.320

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.01 PAGE NO. 9 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty ± 15%

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F		N	N_e	$\bar{X}$	K	S	COMPUTED VALUE in/in/°F x 10^{-6}
-115*							11.0
-330							8.7

*From RT to temperature indicated.

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

32.02 - 268 BRASS ALLOY

Original

32.02

MATERIAL: Brass 268

DRM: M-32
SUPPLEMENT: 2
REVISION: 0
DATE: 12-22-70

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

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MATERIAL: BRASS 268

DRM: 32.02

REVISION: 0
DATE: 12-22-70

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

APPROVALS

ORIGINATOR: [signature]

REVIEW: [signature] 12/28/70

CLASSIFICATION: [signature] 28 Dec 70

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 32.02 PAGE NO. 2 DATE 12-22-70 MATERIAL Brass Alloy 268

CONDITION Annealed TEST DIRECTION All

SPEC. NOS. ASTM 134 FORM All

DATA BASIS Category C COMMENT 65% Cu

PROPERTY Specific Heat

TEMP °F		C_p BTU/LB/ °F		VARIABILITY %		DATA CATEGORY	REFERENCE
80		.096		± 5		C	1
170		.104		± 5		C	1
260		.109		± 5		C	1
350		.114		± 5		C	1

1. MATERIAL:

Brass 268 has a copper content composition between 63 and 68.5% by weight. The material used was Cu - 36.81% Zn alloy, annealed at 1290°F.

2. DATA ANALYSIS:

The data were obtained from Reference (1), which indicates that a variation in this property can be expected with increasing zinc content. The data listed are suitable for Cu-30% and Cu-35% zinc.

A major change in composition (greater than 5% Zn) is required to effect a change in specific heat at the temperatures listed. A variability in data of $\pm$ 5% due to compositional changes should cover the range of expected values for this property.

The data are rated category "C".

3. REFERENCES:

(1) Y. S. Touloukian, Thermophysical Properties of High Temperature Solid Materials, p. 172, Vol. 2, Part I, Macmillan Co., 1967.

33 - LITHIUM HYDRIDE

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. 33.01 REV. NO. 0

SUBJECT: DESIGN ALLOWABLES FOR THE THERMAL AND PHYSICAL PROPERTIES OF LiH

DATE: 7-17-70

1. SCOPE:

The design allowables for the following properties of LiH are attached:

Specific Heat
Thermal Conductivity
Density

2. TEST MATERIAL:

The data were obtained using material of 99.8% purity.

3. DATA ANALYSIS:

The uncertainty in values for specific heat is ± 10% at temperatures below -320°F and ± 5% at temperature above -320°F. Because specific heat is based on Btu/lb, there is no difference in absolute values which may be attributed to the method of fabrication agglomeration (cast or compact).

The uncertainties of thermal conductivity are ± 20% to 302°F and ± 15% above 302°F. This uncertainty is attributed to conflicting data appearing in the literature. The thermal conductivity will vary in proportion to density and composition of entrapped gases, if any.

The uncertainty in density measurement is ± 10%. Density will vary according to method of agglomeration of powders or, if by casting, by the amount of void formation during freezing. The values of other temperatures are based on room temperature density and thermal expansion.

4. CONCLUSIONS:

The uncertainties for LiH are generally higher than for metals. The data are classified category "C".

APPROVED BY	DATE	PREPARED FOR: L. Shirley DATE:	COMPONENT/ ASSEMBLY IDENT: Shield
PREPARED BY	7/27/70	AUTHORIZED CLASSIFIER	DATE 27 July 70

REV. 0

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 33.01 PAGE NO. 2 DATE 7-17-70 MATERIAL LiH

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM 99.8 LiH

DATA BASIS Category "C" COMMENT Uncertainty ± 10% at temperatures less than -320°F; + 5% above -320°F.

PROPERTY Specific Heat, C_P

TEMP °F		C_P BTU/LB °F					
-420		0					
-320		.1					
-160		.47					
-100		.57					
0		.72					
70		.82					
300		1.08					
560		1.28					
810		1.48					

REFERENCE: Touloukian, Y. S., Thermophysical Properties of High Temperature Solid Materials, Macmillan Co., New York, 1967.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 33.01 PAGE NO. 3 DATE 7-17-70 MATERIAL LiH

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM Compacted 99.2% Dense

DATA BASIS Category "C" COMMENT Uncertainty ± 20% to 302°F; ± 15% above 302°F.

PROPERTY Thermal Conductivity, K

TEMP °F		K BTU/ FT-HR-°F					
122		4.0					
212		3.8					
302		3.5					
392		3.3					
482		3.1					
572		2.98					

REFERENCE: Technical Data Sheet, Lithium Hydride, Foote Mineral Co.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 33.01 PAGE NO. 4 DATE 7-17-70 MATERIAL LiH

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM 100% Dense

DATA BASIS Category "C" COMMENT Uncertainty, ± 5%

PROPERTY Density

TEMP °F		ρ LBS/IN.^{3}					
-360		.0284					
-260		.0283					
-160		.0283					
- 60		.0282					
80		.028					
140		.0279					
240		.0277					
340		.0275					
440		.027					
540		.0271					
740		.0265					

Density will vary according to efficiency of compaction. This property will vary in direct proportion to its room temperature density. In addition, uncertainties in the thermal expansion measurements with densities at temperatures other than RT are calculated, will add to the uncertainty in density values.

36 - 21-6-9 STAINLESS STEEL

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. 36.01 REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR THE 21-6-9 STAINLESS STEEL ALLOY SHEET

DATE: 8-7-70

1. SCOPE:

The following design allowables for the Fe-21% Cr-6% Ni-9% Mn alloy sheet are attached:

Tensile Ultimate Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

All data were obtained from supplier technical literature.

3. DATA ANALYSIS:

To establish room temperature properties after exposure to the simulated brazing cycle, the effect of annealing data for the 21-6-9 alloy was reviewed. A gradual decrease (total 10 ksi) of TUS and TYS is noted when annealing temperature is increased from 1800 to 1950°F. It was estimated that strengths would further decrease 5 ksi by thermal exposure to temperatures above 2000°F.

Values below room temperature (RT to -423°F) were available at the same room temperature tensile ultimate strength level as that selected for the TUS of the brazed material, and, therefore, there was no need to adjust room temperature tensile strength to determine subzero TUS properties. However, it was necessary to adjust TYS room temperature properties to determine subzero TYS properties.

Elevated temperature properties were available; however, these had to be adjusted to account for difference in room temperature baseline properties. Values for the 1600°F temperature were extrapolated on the basis of AISI 347 behavior.

All adjusted TUS and TYS values were discounted by 20% as a conservative statistical estimate of design allowables.

Elongation values were decreased by 20% of published values. The typical elongation at 1600°F was estimated from the elongation curves at lower temperatures.

APPROVED BY / DATE	PREPARED FOR: L. A. Shirley DATE:	COMPONENT/ ASSEMBLY IDENT: Nozzle
PREPARED BY	AUTHORIZED CLASSIFIER / DATE 13 Aug 70	

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 2 OF 5	DRM NO. 36.01 REV. NO. 0

SUBJECT:	TENSILE DESIGN ALLOWABLES FOR THE 21-6-9 STAINLESS STEEL ALLOY SHEET	DATE:	8-7-70

4. CONCLUSIONS:

The data are rated category "C", a conservative estimate of the statistical allowable, according to directive SNPO 69-37.

5. REFERENCES:

(1) Technical Bulletin S-26, Armco 21-6-9 Stainless Steel, Armco Steel Co., Middletown, Ohio, 3/66.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE 72<	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 36.01 PAGE NO. 3 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION L & T

SPEC. NOS. - FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE ksi
-423							196
-320							162
-110							107
RT							82
800							57
1200							45
1600							16

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 36.01 PAGE NO. 4 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Brazed TEST DIRECTION L & T

SPEC. NOS. - FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
-423							151
-320							116
-110							67
RT							45
800							20
1200							18
1600							12

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 36.01 PAGE NO. 5 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Brazed TEST DIRECTION L & T

SPEC. NOS. FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE %
-423							12
-320							24
-110							37
RT							34
800							33
1200							21
1600							14

COMMENTS:

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. 36.02 REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR 21-6-9 STAINLESS STEEL FORGINGS

DATE: 8-7-70

1. SCOPE:

The following design allowables for the Fe-21 Cr-6 Ni-9 Mn stainless steel alloy forgings are attached:

Tensile Ultimate Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

The basic data were obtained from supplier technical literature.

3. DATA ANALYSIS:

The tensile ultimate and tensile yield values at room and subzero temperatures were based on typical values obtained on a 4-3/4 in. thick slab. The values were adjusted (1) to compensate for the thermal effects of the simulated brazing cycle and differences in room temperature properties. These values were then decreased by 20% to obtain a conservative estimate of the statistical allowable values.

The 600°F values were obtained using the same procedure as for subzero properties except that sheet typical values were used as the base.

4. CONCLUSIONS:

The data are classified category "C", a conservative estimate of the statistical allowables, according to directive SNPO TD 69-37.

5. REFERENCES:

(1) DRM M-36A, Tensile Design Allowables for the 21-6-9 Stainless Steel Alloy Sheet, dated 8-7-70.

APPROVED BY / DATE	PREPARED FOR: L. A. Shurley DATE:	COMPONENT/ ASSEMBLY IDENT: N033/e
PREPARED BY	AUTHORIZED CLASSIFIER / DATE: 13 Aug 70	75<

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 36.02 PAGE NO. 2 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION Circumferential and Radial

SPEC. NOS. - FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
-423							186
-320							154
-110							102
RT							78
600							61

COMMENTS: Adjusted values of data contained in Armco Technical Data Bulletin S-26, Armco Steel Corp., Middletown, Ohio, 3/66.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 36.02 PAGE NO. 3 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION Circumferential and Radial

SPEC. NOS. - FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE ksi
-423							141
-320							108
-110							62
RT							42
600							24

COMMENTS: Adjusted values of data contained in Armco Tehcnical Data Bulletin S-26, Armco Steel Corp., Middletown, Ohio, 3/66.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 36.02 PAGE NO. 4 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION Circumferential and Radial

SPEC. NOS. - FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE %
-423							12
-320							20
-110							45
RT							40
600							33

COMMENTS: Adjusted values of data contained in Armco Technical Data Bulletin S-26, Armco Steel Corp., Middletown, Ohio, 3/66.

37 - PHOSPHOR BRONZE

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 3	DRM NO. 37.01 REV. NO. 0

SUBJECT: DESIGN ALLOWABLES FOR THE THERMOPHYSICAL PROPERTIES OF PHOSPHOR BRONZE "A"

DATE: 8-3-70

1. SCOPE:

The design allowables for the following properties of Phosphor Bronze "A" are attached:

Specific Heat
Thermal Conductivity

2. TEST MATERIAL:

The specific heat data were obtained from pure copper and pure tin. The thermal conductivity data were estimated from curves of pure copper and a single data point for phosphor bronze at room temperature.

3. DATA ANALYSIS:

The specific heat data for Phosphor Bronze "A" were estimated from the pure metals, copper and tin, by means of the Neumann-Kopp rule.

The thermal conductivity data were estimated by using a room temperature data point for phosphor bronze "A" and following the shape of the conductivity curve for pure copper to near absolute zero.

Uncertainty levels for both thermal conductivity and specific heat were placed at ± 20% for -423°F and ± 15% for the remaining data points.

4. CONCLUSIONS:

Data were established by engineering judgment from available information. No category is required.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

80a

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 37.01 PAGE NO. 2 DATE 8-3-70 MATERIAL Phosphor Bronze "A"

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS No Category Required COMMENT _____

PROPERTY Thermal Conductivity

TEMP °F		BTU-FT / FT^2 HR °F		VARIABILITY			
0		46		± 15%			
-320		20		± 15%			
-423		6		± 20%			

REFERENCE: Powell, R. L. and Blanpied, W. A., "Thermal Conductivity of Metals and Alloys at Low Temperature, a Review of the Literature," NBS Circular 556, dated 1 September 1954.

80k

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 37.01 PAGE NO. 3 DATE 8-3-70 MATERIAL Phosphor Bronze "A"

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS No Category Required COMMENT _____

PROPERTY Specific Heat

TEMP °F		C_P BTU/LB °F		VARIABILITY			
80		9.12×10^{-2}		± 15%			
-320		1.37×10^{-2}		± 15%			
-423		4.0×10^{-3}		± 20%			

REFERENCE: T. S. Touloukian, Data Book, Thermophysical Properties Center, Purdue University, Lafayette, Indiana.

81<

MATERIAL: Bronze

DRM: 37.02

REVISION: 0
DATE: 2-2-71

CONTENTS

APPROVALS

ORIGINATOR: R. J. Kalfsbeek

REVIEW: D. Rauschenberger 8 Feb 71

CLASSIFICATION: C W Lum 8 Feb 71

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 37.02 PAGE NO. 2 DATE 2-2-71 MATERIAL Bronze

CONDITION Annealed TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS Category "D" COMMENT

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F		IN/IN/°F x 10^{-6}*	s	k	ALLOWABLE IN/IN/°F x 10^{-6} MIN. MAX.	DATA CATEGORY	REFERENCE
-423		9.5	± .215	2.306	9.0/10.0	D	3
-320		9.9	± .217	2.306	9.4/10.4	D	1, 2
572		9.9	± .217	2.306	9.4/10.4	C	1, 2

*From room temperature (75°F) to temperature indicated.

1. MATERIAL

The data are applicable to annealed bronze having a nominal composition of 95% Cu - 5% Sn by weight.

2. DATA ANALYSIS

Elevated temperature thermal expansion data for Cu - 5% Sn bronze was available in the literature. The data for room temperature to -423°F were estimated by a comparison of the expansion characteristics of pure copper and bronze. From -320 to approximately 600°F, the expansion of copper is essentially linear in character. The expansion of bronze is slightly higher than that of copper and by assuming linearity to -320°F, elevated temperature data were extrapolated downward.

Variations due to chemistry and experimental error are estimated to result in a standard deviation of $\pm$ .217 in./in./°F. The data RT to 572°F are classified category "C" and from RT to -423°F, category "D".

3. REFERENCES

(1) Metals Handbook, 8th Edition, American Society for Metals.

(2) Y. S. Touloukian, Thermophysical Properties of High Temperature Solid Materials, Vols. I and II, 1967 Edition.

(3) Cryogenic Materials Data Handbook, Vol. II, Aug. 1968.

38 - 22-13-5 STAINLESS STEEL

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. 38.01 REV. NO. 0

SUBJECT: DESIGN ALLOWABLES FOR ALLOY 22-13-5 STAINLESS STEEL BAR

DATE: 8-7-70

1. SCOPE:

The design allowable values for the following properties of alloy 22-13-5 stainless steel are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

The test data were taken from 1-in. diameter annealed bar conforming to the chemical requirements of alloy 22-13-5 stainless steel alloy.

3. DATA ANALYSIS:

The referenced product data sheet values were reduced by 20% to provide a conservative estimate for design allowable values.

4. CONCLUSIONS:

The data are classified category "C" according to interpretation of TD 69-37, a conservative engineering estimate of the design allowables.

5. REFERENCE:

(1) Armco Product Data Sheet S-45, Armco Steel Corp., Advanced Materials Division, Baltimore, Maryland.

APPROVED BY DATE	PREPARED FOR: L. A. Shurley DATE:	COMPONENT/ ASSEMBLY IDENT: Nozzle
PREPARED BY J. E. Kahle	AUTHORIZED CLASSIFIER DATE 7 Aug 70	85

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 38.01 PAGE NO. 2 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 1-In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY Tensile Ultimate Strength

TEMP °F		DESIGN VALUE ksi					
-320		181					
-100		117					
75		97					
600		84					
800		78					
1000		74					
1200		66					
1350		56					
1500		42					

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 38.01 PAGE NO. 3 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 1-In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY TENSILE YIELD STRENGTH

TEMP °F		DESIGN VALUE ksi					
-320		102					
-100		68					
75		52					
600		37					
800		36					
1000		33					
1200		33					
1350		32					
1500		27					

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 38.01 PAGE NO. 4 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 1-In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY Elongation

TEMP °F		DESIGN VALUE % IN 2 IN.					
-320		33.0					
-100		39.6					
75		37.2					
600		30.0					
800		24.0					
1000		31.6					
1200		28.4					
1350		31.2					
1500		34.4					

39 - BERYLLIUM COPPER

MATERIAL: BeCu

DRM: 39.01

REVISION: 0
DATE: 12-22-70

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

APPROVALS

ORIGINATOR: Ralph Stoltz

REVIEW: D J Lammeyer 12/28/70

CLASSIFICATION: A W Lemmon 31 Dec 70

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 39.01 PAGE NO. 2 DATE 12-22-70 MATERIAL Cu - 1.8% Be

CONDITION Solution Anneal & Fully Aged TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS C COMMENT

PROPERTY Specific Heat

TEMP °F		BTU/LB/ °F		VARIABILITY %		DATA CATEGORY	REFERENCE
80		.110		± 15		C	1
170		.111		± 15		C	1
260		.112		± 15		C	1
350		.116		± 15		C	1

1. MATERIAL:

The material has a composition of Cu - 1.8% Be (nominal 2%) in the quenched and fully aged condition.

2. DATA:

The data were obtained by extending the quenched and tempered curve from 400°K to 300°K as it appears in Reference (1). The data are classified category "C" because of this extrapolation.

The variability can be as high as ± 15% because a small weight percent of Be in Cu is a high atom percent and since the specific heat of Be is approximately 5 times that of Cu, from the Neumann Kopp rule, large variability can be expected by small changes in composition.

3. REFERENCES:

(1) Y. S. Touloukian, Thermophysical Properties of High Temperature Solid Materials, Vol. II, Macmillan Co., 1965.

41 - INVAR 36

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

APPROVALS

ORIGINATOR: Ralph Holgate

REVIEW: N. J. Ramenofsky 11/24/70

CLASSIFICATION: [illegible] 24 Nov 70 UNCLASSIFIED

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 41.01 PAGE NO. 2 DATE 11-23-70 MATERIAL INVAR 36

CONDITION Annealed TEST DIRECTION Longitudinal

SPEC. NOS. FORM 3 In. Bar or Plate

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength

TEMP °F	TUS	ESTIMATED ks	ALLOWABLE ksi	CATEGORY	REFERENCE		
RT	65	15	50	C	1 & 2		
-100	77	17	60	C	1 & 2		
-320	103	23	80	C	1 & 2		
-423	116	26	90	C	1 & 2		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 41.01 PAGE NO. 3 DATE 11-23-70 MATERIAL INVAR 36

CONDITION Annealed TEST DIRECTION Longitudinal

SPEC. NOS. FORM 3 In. Bar or Plate

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength

TEMP °F	TYS	ESTIMATED ks	ALLOWABLE ksi	CATEGORY	REFERENCE		
RT	40	5	35	C	1		
-100	45	5	40	C	1 & 2		
-320	56	10	46	C	1 & 2		
-423	69	10	59	C	1 & 2		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 41.01 PAGE NO. 4 DATE 11-23-70 MATERIAL INVAR 36

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 3 In. Bar or Plate

DATA BASIS Category "D" COMMENT

PROPERTY Compressive Yield Strength

TEMP °F	AVERAGE	ESTIMATED ks	ALLOWABLE ksi	CATEGORY	REFERENCE		
RT	50	10	40	D	1		
-100	55	10	45	D	1 & 2		
-320	61	10	51	D	1 & 2		
-423	76	10	66	D	1 & 2		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 41.01 PAGE NO. 5 DATE 11-23-70 MATERIAL INVAR 36

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 3 In. Bar or Plate

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Elongation

TEMP °F	AVERAGE	ESTIMATED ks	ALLOWABLE ksi	DATA CATEGORY	REFERENCE		
RT	40	10	30	C	2		
-100	50	10	40	C	2		
-320	52	10	42	C	2		
-423	40	10	30	C	2		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 41.01 PAGE NO. 6 DATE 11-23-70 MATERIAL INVAR 36

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 3 In. Bar or Plate

DATA BASIS Category "C" COMMENT

PROPERTY Modulus of Elasticity

TEMP °F	TYPICAL E X 10^6 psi	VARIABILITY	CATEGORY	REFERENCE			
RT	21	± 5	C	2			
-100	20.2	± 5	C	2			
-320	19.7	± 5	C	2			
-423	19.5	± 5	C	2			

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 41.01 PAGE NO. 7 DATE 11-23-70 MATERIAL INVAR 36

CONDITION Annealed TEST DIRECTION Longitudinal

SPEC. NOS. FORM 3 In. Bar or Plate

DATA BASIS Category "B" COMMENT

PROPERTY Mean Coefficient of Thermal Expansion

TEMP °F	AVERAGE* α IN./IN.°F X 10^{-6}	VARIABILITY	DATA CATEGORY	REFERENCE			
-100	.655	± 5	B	3			
-200	.86	± 5	B	3			
-320	.93	± 5	B	3			
-423	.77	± 10	B	3			

*From RT (68°F) to temperature indicated.

1. MATERIALS:

The data are applicable to 3-in. rounds or plate in the fully annealed conditions.

2. DATA ANALYSIS:

Room temperature data for UTS, TYS, and elongation for annealed material were available from several sources and were in general agreement. For data below room temperature, Reference (2) was used exclusively, although the data listed were for 12-15% cold reduced .750-in. round bar. A ratio was calculated for room temperature properties to account for the differences in strength produced by cold working. It was then assumed that the ratio was at all temperatures below -70°F. Different ratios were obtained for F_{tu}, F_{ty}, and elongation. An estimated "ks" factor was used to determine a conservative allowable for each property.

No data were available for the compressive yield strength, and it was estimated to be 10% higher than the calculated tensile yield strength at all temperatures. An estimated ks factor was subtracted to obtain the allowable.

Examination of modulus data for the temperature range 70 to -423°F showed cold working had a minor influence on this property, and the data from Reference (2) were used. The variability in this property was estimated to be $\pm$ 5%.

Thermal expansion data of annealed Invar between RT and -423°F were available from a reliable source [Reference (3)], and mean coefficients of thermal expansion were calculated using these data. These data with their estimated variability are classified category "B".

3. REFERENCES:

(1) "Mechanical and Physical Properties of Invar and Invar-Type Alloys," DMIC Memorandum 207, Battelle Memorial Institute, August 1965.

(2) Section F5ab, Vol. II, Cryogenic Material Data Handbook (Revised), AFML-TDR-64-280, Supplement 4, August 1968.

(3) 27th Progress Report, NBS No. 9291, NBS, Boulder Labs, September 1967.

42 - MONEL K-500

MATERIAL: MONEL K-500

DRM: 42.01

REVISION: 0
DATE: 12-8-70
PAGE 1 OF 8

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

APPROVALS

ORIGINATOR: Ralph J. Hatfield CED.ifm

REVIEW: N. J. Lamerman 12/10/70

CLASSIFICATION: Unclassified

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.01 PAGE NO. 2 DATE 12-8-70 MATERIAL MONEL K-500

CONDITION Cold Drawn and Aged TEST DIRECTION

SPEC. NOS. FORM $\leq$ .25 In. Dia. Wire

DATA BASIS COMMENT Spring Temper

PROPERTY Ultimate Tensile Strength

TEMP °F		NOMINAL TUS		ESTIMATED ks	ALLOW-ABLE ksi	CATEGORY	REFERENCE
RT		197		17	180	C	1
-320		220		30	190	D	1
-423		240		40	200	D	1

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.01 PAGE NO. 3 DATE 12-8-70 MATERIAL MONEL K-500

CONDITION Cold Drawn and Aged TEST DIRECTION

SPEC. NOS. FORM ≤ .25 In. Dia. Wire

DATA BASIS COMMENT Spring Temper

PROPERTY Tensile Yield Strength

TEMP °F		AVERAGE	ESTIMATED ks	ALLOW-ABLE ksi	DATA CATEGORY	REFERENCE	
RT		190	30	160	C	1	
-320		205	30	175	D	1	
-423		230	40	190	D	1	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.01 PAGE NO. 4 DATE 12-8-70 MATERIAL MONEL K-500

CONDITION Cold Drawn and Aged TEST DIRECTION

SPEC. NOS. FORM $\leq$ .25 In. Dia. Wire

DATA BASIS COMMENT Spring Temper

PROPERTY Elongation

TEMP °F		AVERAGE	ESTIMATED ks	ALLOW-ABLE %	DATA CATEGORY	REFERENCE	
RT		3	2	1	C	1	
-320		5	2	3	D	1	
-423		4	2	2	D	1	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.01 PAGE NO. 5 DATE 12-8-70 MATERIAL MONEL K-500

CONDITION Cold Drawn and Aged TEST DIRECTION

SPEC. NOS. FORM $\leq$ .25 In. Dia. Wire

DATA BASIS COMMENT Spring Temper

PROPERTY Torsional Breaking Strength

TEMP °F		NOMINAL ksi	ESTIMATED ks	ALLOW-ABLE ksi	CATEGORY	REFERENCE	
RT		137	27	110	C	1	
-320		153	23	130	D	1	
-423		167	27	140	D	1	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.01 PAGE NO. 6 DATE 12-8-70 MATERIAL MONEL K-500

CONDITION Cold Drawn and Aged TEST DIRECTION

SPEC. NOS. FORM ≤ .25 In. Dia. Wire

DATA BASIS COMMENT Spring Temper

PROPERTY Torsional Proportional Limit

TEMP °F		NOMINAL ksi	ESTIMATED ks	ALLOW-ABLE ksi	CATEGORY	REFERENCE	
RT		75	25	50	C	1	
-320		84	24	60	D	1	
-423		91	21	70	D	1	

1. TEST MATERIAL:

The data are based on values obtained from tests using .148-in. wire, 65% cold reduction, and aged at 980°F/6 hours plus 900°F/6 hours.

2. DATA ANALYSIS:

The room temperature properties of tensile strength, yield strength, elongation, torsional breaking strength, and torsional proportional limit are as reported in Reference (1). The ks factor was estimated to allow for variability due to composition, heat treat response and to obtain a conservative value of design allowable at the 99/95 reliability requirements.

No data were available for low temperature properties for wire in the spring temper and aged condition; low temperature data were available for .063-in. thick sheet. To establish an allowable for F_{tu} and F_{ty} at low temperatures, a ratio was established using RT values for aged sheet. For cold drawn and aged wire, the low temperature values of sheet were then multiplied by this ratio. It was assumed that the tensile behavior of both forms of this alloy would be similar; the ks factor was increased to 30 ksi and 40 ksi at -320 and -423°F, respectively, to offset the unknown aspects of this assumption. Elongation values at low temperatures were based on engineering estimates using the behavior of sheet at these temperatures as a guide.

The torsional breaking strength (TBS) and torsional proportional limits (TPL) for low temperature were calculated using the room temperature ratio for TBS/UTS = .695 and TPL/UTS = .380. It was assumed that these ratios would apply at all temperatures. The ks factors are engineering estimates.

The data contained in this DRM are applicable only to material processes as described above (Test Material). Major changes in wire diameter, reduction, and aging treatments will result in significant changes in properties.

Room temperature data are classified category "C"; the low temperature properties were estimated using a different form and condition, and, therefore, these data are classified category "D".

3. REFERENCES:

(1) Technical Bulletin, Monel Nickel-Copper Alloys, Huntington Alloy Products Division, International Nickel Company, Inc., October 1969.

MATERIAL: K Monel 500

DRM: 42.02

REVISION: 0
DATE: 12-17-70

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

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APPROVALS

ORIGINATOR:

REVIEW: 12/21/70

CLASSIFICATION:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.02 PAGE NO. 2 DATE 12-17-70 MATERIAL K-Monel 500

CONDITION Hot Finished or Cold Drawn, Annealed and Aged. TEST DIRECTION Longitudinal

SPEC. NOS. FORM Rod and Bar

DATA BASIS COMMENT

PROPERTY Tensile Ultimate Strength

TEMP °F	NOMINAL UTS ksi	ESTIMATED ks	DESIGN ALLOWABLE	DATA CATEGORY	REFERENCE		
-423	173	20	153	C	2		
-320	158	20	138	C	2		
-100	145	15	130	C	2		
RT	130	15	115	C	1		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.02 PAGE NO. 3 DATE 12-17-70 MATERIAL K-Monel 500

CONDITION Hot Finished or Cold Drawn, Annealed and Aged TEST DIRECTION Longitudinal

SPEC. NOS. FORM Rod and Bar

DATA BASIS COMMENT

PROPERTY Tensile Yield Strength

TEMP °F	NOMINAL TYS ksi	ESTIMATED ks	DESIGN ALLOWABLE, ksi	DATA CATEGORY	REFERENCE		
-423	118	20	108	C	2		
-320	105	20	85	C	2		
-100	95	15	80	C	2		
RT	85	15	70	C	1		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.02 PAGE NO. 4 DATE 12-17-70 MATERIAL K-Monel 500

CONDITION Hot Finished or Cold Drawn, Annealed and Aged TEST DIRECTION

SPEC. NOS. FORM Rod and Bar

DATA BASIS COMMENT

PROPERTY Elongation

TEMP °F	NOMINAL e %	ESTIMATED ks	DESIGN ALLOWABLE, %	DATA CATEGORY	REFERENCE		
-423	38	10	28	C	2		
-320	40	10	30	C	2		
-100	33	8	25	C	2		
RT	30	8	22	C	1		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.02 PAGE NO. 5 DATE 12-17-70 MATERIAL K-Monel 500

CONDITION Hot Finished or Cold Drawn, Annealed and Aged TEST DIRECTION

SPEC. NOS. FORM Rod and Bar

DATA BASIS Category B COMMENT

PROPERTY Modulus of Elasticity

TEMP °F	NOMINAL VALUE psi x 10^6	VARIABILITY	DATA CATEGORY	REFERENCE			
-423	27.0	± 5%	B	2			
-320	26.5	± 5%	B	2			
RT	26.0	± 5%	B	1			

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 42.02 PAGE NO. 6 DATE 12-17-70 MATERIAL K-Monel 500

CONDITION Hot Finished or Cold Drawn, Annealed and Aged TEST DIRECTION

SPEC. NOS. FORM

DATA BASIS COMMENT

PROPERTY Poisson's Ratio

TEMP °F	NOMINAL	VARIABILITY %	DATA CATEGORY	REFERENCE			
-423	.32	± 10%	C	-			
-320	.32	± 10%	C	-			
RT	.32	± 10%	B	1			

1. MATERIAL:

The test material is hot rolled or cold drawn rod and bar, annealed, and aged by a step process to obtain maximum mechanical properties. The aging process usually consists of the following:

Annealed, 1900°F/1 hour

Aged, 1100°F/16 hours

Furnace Cool to 1000°F and hold 6 hours

Air cool to room temperature

Variations in the above treatment will result in properties other than those listed.

2. DATA ANALYSIS:

The room temperature TUS and TYS data are the nominal properties for bar and rod regardless of size; higher properties can be obtained in small sizes. The ks factor for room temperature values is estimated to be 15 ksi. Data for properties below room temperature were obtained from Reference (2). There was a difference in room temperature properties and to account for this difference a ratio was calculated and applied to all other temperatures. The ks factor for -100°F was estimated to be 15 ksi, and for -320 and -423°F, the ks factor was increased to 20 ksi.

The ductility of this alloy is increased as temperature is decreased to -423°F. The ks factor was estimated to be approximately 25-30% of the total value of elongation.

The modulus of elasticity values for 80°F were obtained from Reference (1) and for other temperatures, Reference (2). The difference in RT values from the two sources is within the 5% predicted variability.

An RT value for Poisson's ratio was available [Reference (1)] and this property was assumed to be invariant with temperature.

The mechanical property data were classified category "C". The physical properties, E at RT, -320 and -423°F, and Poisson's ratio at RT were classified category "B". Where data were estimated, the data were classified category "C".

3. REFERENCES:

(1) Technical Bulletin: "Monel, Nickel-Copper Alloys," Huntington Alloy Products Division, The International Nickel Co., Inc., October 1969.

(2) Cryogenic Materials Data Handbook (Revised), Supp. IV, Vol. II, AFML-TDR-64-280 (Revised), August 1968.

45 - 3% SILICON TRANSFORMER STEEL

MATERIAL: 3% Si Transformer Steel

DRM: 45.01

REVISION: 0
DATE: 12-22-70
PAGE 1 OF 3

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

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APPROVALS

ORIGINATOR: Ralph [signature]

REVIEW: [signature] 12/22/70

CLASSIFICATION: [signature] 22 Dec 70

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 45.01 PAGE NO. 2 DATE 12-22-70 MATERIAL 3% Si Transformer Steel

CONDITION Annealed TEST DIRECTION All

SPEC. NOS. FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Specific Heat

TEMP °F		C_p BTU/LB/ °F		VARIABILITY %		DATA CATEGORY	REFERENCE
80		.118		± 5		C	1
170		.120		± 5		C	1
260		.122		± 5		C	1
350		.125		± 5		C	1

1. MATERIAL:

The material has a nominal composition of 3% Si (2.78%), .35% Mn, .07% C, and .06 Al and .024% P.

2. DATA:

The data were obtained from Reference (1). Although the Si content varied from 1 to 2.78% at the lower temperatures, the variability was within 5% limits noted.

The data are classified category "C".

3. REFERENCES:

(1) Y. S. Touloukian, Thermophysical Properties of High Temperature Solid Materials, p. 421, Vol. 3, Macmillan Co. 1967